

zero. Both quantities are evaluated in a single operation which consists in fitting a straight line to plotted pyrheliometric observations of the solar intensity at varying air masses, and prolonging it to the zero of abscissas or air mass zero. The data show pronounced correlation in respect to the minor day-to-day fluctuations, as shown by the method of correlation by variations, while by the usual method of correlation by deviations from the mean, little correlation results, owing to the existence of long-period changes in the transmission coefficient without corresponding changes in the solar intensity.

*Variation in the mean.*—The mean may vary either systematically through long-period fluctuations or accidentally, as by a change of hours of observation, or exposure of instruments, rendering the data nonhomogeneous. A gradual or abrupt change in the regimen of

a river or an increase in the number of crop reporting points in a State over a term of years or an increase in yields due to cultivation are further examples of such actual or accidental changes in the mean. Frequently it is difficult or impossible to distinguish between an actual change in the mean and a true secular change, both of which may cause deviations which are not present in the variations of another variable with which a relation is sought. The usual method of correlation by deviations yields results more or less spurious. In all such cases the method of correlation by variations should be employed, since it is quite independent of nonsimultaneous changes in the means of the two variables, either accidental or systematic. The usual method by deviations is, however, appropriate in the case of systematic changes if the secular change be first eliminated by taking deviations from means varying with the general trend.

## THE TEXAS FLOODS OF SEPTEMBER, 1921.

### GENERAL DISCUSSION.

By B. BUNNEMEYER, Meteorologist.

[Weather Bureau, Houston, Tex., Oct. 10, 1921.]

627.41 (764)

Torrential rains in southern and central Texas from September 8 to 10, inclusive, 1921, resulted in phenomenally rapid floods in streams and lowlands, especially in Bexar, Travis, Williamson, Bell, and Milam Counties, and caused the death, so far as is known, of 215 persons and property loss estimated at over \$19,000,000. This exceeds the havoc wrought by the record-breaking floods of December, 1913, when 177 persons lost their lives and property valued at nearly \$9,000,000 was destroyed. But in December, 1913, there were practically no crops in the fields.

The heaviest precipitation was reported from Taylor, Williamson County, where 23.11 inches occurred in 24 consecutive hours, September 9–10, which is the greatest 24-hour rainfall of record for the State of Texas, the previous record being 20.60 inches at Montell, Uvalde County, on June 28–29, 1913.

Throughout the stricken area traffic by railroad, street car, or other conveyances was interrupted by washouts, loss of bridges, and accumulation of debris; telegraph, telephone, electric light, and other public services were crippled, and numerous small houses and other structures were carried off by the currents that swept through cities and rural districts, resulting in the loss of many lives. Much other damage was done, largely to crops, mostly corn and cotton. Considerable damage was also caused by violent thunderstorms and squalls occurring in various localities during the downpour, although it was overshadowed by the havoc due to the flood.

While creeks and other tributaries rose to appalling heights, the trunk streams were much less seriously affected than was anticipated from the deluge, the redeeming features being a previously dry soil and low streamflow. The run-off was swift and much of the back water did not return to the streams, resulting in a rapid diminution of the volume of water rushing toward the Gulf of Mexico. The subsidence of the flood wave on the Brazos River was so rapid that flood stage was not attained in the lower reaches of that stream at or below Rosenberg, while at Valley Junction, where the water poured in from the Little River, the stream was 14.2 feet above flood stage and only 0.8 foot below the record high watermark of the December, 1913, flood.

*Cause of the rains.*—Evidence is strong that the precipitation was the result of the breaking-up in Texas of the disturbance that moved westward toward the Mexican coast south of Tampico on September 7, 1921. Although the distribution of the pressure was such that the storm could not be charted, the shifting winds, the progressive northeastward extension of the rainfall area, and the profound agitation of the atmosphere as evidenced by violent squalls and thunderstorms over the stricken sections, can hardly be ascribed to any other cause. The storm apparently moved in from Mexico over Webb County and passed in a northeasterly direction over Bexar, Comal, Hays, and Travis Counties into Williamson, Bell, and Milam Counties where it abruptly dissipated. Milam County borders on the west bank of the Brazos River, and there was very little precipitation along the east bank of that stream. An area of high pressure of apparently feeble energy backing in over eastern Texas was probably a contributory cause of the record breaking rains and their abrupt termination near the Brazos River. While the rains were disastrous to life and property over a large area, there were many localities in southern Texas where they proved beneficial by relieving the drought, reviving ranges, and providing stock water.

*Warnings.*—The flood waters accumulated so rapidly in creeks and lowlands that residents were taken completely by surprise. Warnings of impending rises were issued, however, immediately upon the receipt of rainfall reports to the main streams on which river stations are maintained. On the morning of September 9, to the lower Rio Grande from Rio Grande City to Brownsville; and on September 10 to the Colorado below Austin, and to the Brazos from Valley Junction to Richmond, with injunctions to keep live stock from the lowlands and protect other interests. Warnings were repeated on September 11 to residents along the Colorado and Brazos, and extended along the latter stream from Richmond to Freeport. Thereafter residents were kept informed daily of the progress of the floods until danger was over. Similar warnings and injunctions were issued September 11 to the lower Guadalupe. Earlier warnings were not advisable as there were no data available to justify them.

Reports received up to that time from the upper Guadalupe drainage basin indicated rainfall too small to affect the streamflow, considering the August drought. Long distance calls were numerous and planters heeded the warnings even after it became apparent that there would be no danger in the coast sections for, as some of

with river 8.6 feet and rising, and points below were warned accordingly. The flood wave moved downstream at a rapid rate, Rio Grande City having a rise of 17.8 feet in 24 hours to a stage of 18 feet, or 3 feet above flood stage, by the morning of September 10, which was the maximum stage reported. On the morning of

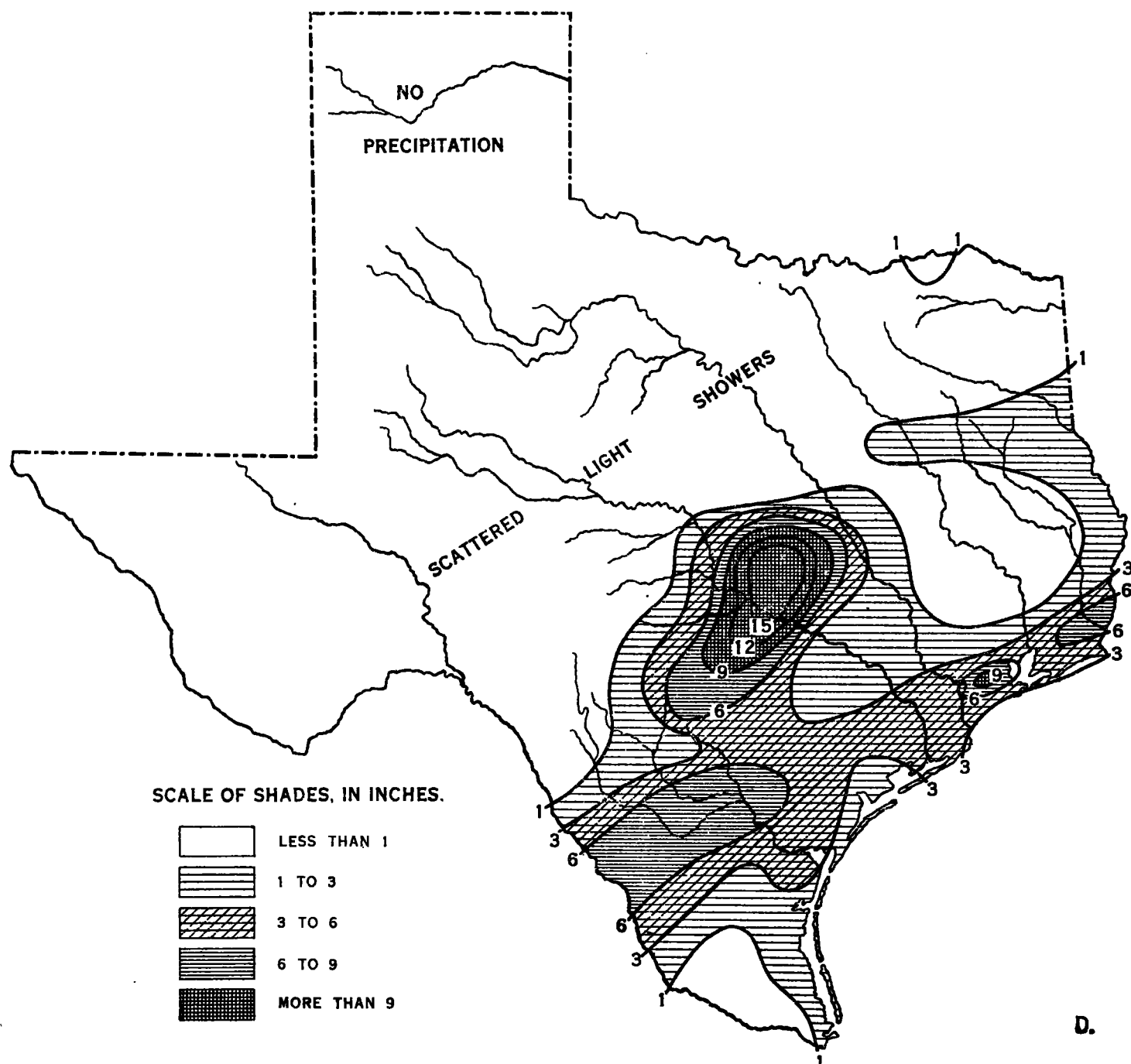


FIG. 1.—Texas rainfall, Sept. 7-11, 1921.

them stated, "the corn has to be hauled in and we might as well do it now as later."

River service is not maintained on the Nueces, San Antonio, or Little Rivers, but reports of all heavy rains over the Little River drainage were repeated to Cameron as soon as received at this office.

*Flood of the Rio Grande.*—On September 9, Laredo reported a rainfall of 6 inches for the preceding 24 hours

September 11 the stream was within banks. The crest of the rise passed Mission on September 11 with a maximum stage of 17.5 feet, which is well below flood stage. There was no damage from the rise.

*Flood of the Guadalupe.*—Unusually heavy rains over the San Marcos and upper Guadalupe drainage basins resulted in a rapid rise of the stream at Gonzales. Blanco reported a total precipitation of 7.85 inches, San Marcos

of 11.50, and New Braunfels of 9.56 inches, while several other stations reported amounts ranging from 2 to 3 inches. The initial rise at Gonzales amounted to 21.9 feet from 1.3 feet at 7 a. m. September 10 to 23.2 feet at 7 a. m. September 11. (Flood stage, 22 feet.) The crest of the flood occurred at 7 p. m. of that date, with a stage of 31.4 feet and stream approximately one-fourth mile wide. The stream fell rapidly during September 13, and by 7 a. m. next morning was down to 7.1 feet. The damage from the high water consisted principally of the loss of low valley corn. There was no loss of live stock. County authorities estimate the damage for the entire county of Gonzales at \$3,500.

The flood wave reached Victoria September 13 with an initial rise of 13 feet in 24 hours and to a stage of 14.7 feet. Thereafter the rise was much slower and continued until September 16, when the gage showed 20.5 feet, or 4.5 feet above flood stage, which was the maximum stage reported. The subsidence of the high water was rapid and by the morning of September 17 the stream was down to 8.1 feet. There was only a slight overflow at Victoria from water backing into low places and no damage.

While the flood loss on the Guadalupe from Gonzales to its mouth was insignificant, considerable damage occurred from the rains in Blanco, Hays, Comal, and Guadalupe counties, the total being estimated at \$218,500.

*Flood of the Colorado.*—Terrific rains on September 9 and 10 in Burnet and Travis counties caused a rapid flooding of the Colorado River below Austin. Fairland in Burnet County reported 8.70 inches for the two days, Marble Falls in the same county, 16.50 inches, and Austin in Travis County, 19.03 inches. During the 24 hours ending 7 a. m. September 10 the rainfall at Austin was 18.25 inches. Notwithstanding the heavy rains in Burnet County, the maximum stage reported from Marble Falls was only 3.2 feet. At Austin, however, the stream rose rapidly from 0.8 foot at 7 a. m. September 9 to 19.0 feet, or 1 foot above flood stage, by midnight of September 10, which was the maximum stage attained. The overflow of the Colorado caused no damage at Austin, all losses being caused by the floods of creeks and lowlands before the waters reached the main stream. The damage to highways and bridges was \$600,000, to crops in the fields \$225,000, and to live stock \$25,000. Violent thunderstorms and squalls caused an additional damage of \$30,000 at Creedmor and Austin.

The flood wave moved rapidly downstream, and at Smithville, Bastrop County, the stream rose from 1.4 feet on the evening of September 9 to 22.1 feet by 7 p. m. September 10 (flood stage 24 feet). The crest of the flood passed at noon, September 11, with stage 26.0 feet. The subsequent fall was equally rapid, and by 9 a. m. September 12 the water was within banks, and 10 hours later down to 12 feet. Smithville is located on a bluff forming the right or south bank of the river, but the left bank is low and the lowlands on that side were submerged for a distance varying from one-half to two miles at the peak of the flood. The damage to crops is estimated at \$6,000, including loss of farm animals, and damage to roads and bridges at \$2,000. That the crop loss was not greater is due to the fact that the first picking of the cotton crop had been made and that about 65 per cent of the corn had been gathered.

At La Grange, Fayette County, which is traversed by the Colorado after it leaves Bastrop County, the damage to crops is estimated at \$15,000, loss of live stock at \$1,500, and damage to other property at \$750; but

reports property valued at \$20,000 saved by warnings. Much corn in the lowlands could have been saved if the fields had not been so wet. As it was it took four horses or mules to a wagon to haul in corn.

At Columbus, the lowest river station on the Colorado, the stream rose from 5.4 feet September 10 to 23 feet by next morning and continued to rise until about 7 a. m. September 13, when the maximum height, 33.8 feet, or 5.8 feet above flood stage, was recorded. During the next 24 hours the stream fell 15.3 feet. The damage to crops and property was reported very small, and there was no loss of live stock, nor was any damage reported from places below Columbus. Evidently the flood wave flattened out rapidly.

*Flood of the Brazos.*—This flood was remarkable from the fact that it was caused by tremendous rains over a single tributary, the Little River, which empties into the Brazos just above Valley Junction, and that the large volume of water spread out at an exceedingly rapid rate as it rushed downstream.

The Little River with its tributaries drains an area of probably 7,000 square miles, but in this case only the lower portions of this area, comprising Williamson, Bell, and Milam Counties, were flooded from the terrific downpour. The total rainfall for two days amounted to 23.98 inches at Taylor and to 14.43 inches at Georgetown, both located in Williamson County; while Temple, in Bell County, recorded for the same period 11.55 inches, and Cameron, in Milam County, 13.30 inches. The Little River and tributaries rose to unprecedented heights. At Georgetown the San Gabriel River and Berrys Creek were reported over 7 feet higher than ever known before. The damage was great and two deaths occurred. Some houses and much corn and cotton were washed away, but pastures were benefited.

At Taylor at the height of the flood the water ran from 1 to 3, and in some places 4 feet deep through the streets, washing up pavements and flooding cellars and basements. Bridges and culverts were carried away, and many small houses in the Mexican section south of the business district were washed from their foundations. The greatest damage and loss of life occurred along the San Gabriel River and Brushy Creek, which rose so rapidly that the people were trapped and perished in their own homes. The waters of Brushy and Mustang Creeks, both passing south of Taylor, met and formed a current 10 miles wide. Violent thunderstorms with squalls occurred during the downpour. The property loss in the vicinity of Taylor amounted to \$93,000 and 87 persons, mostly Mexicans, perished in the flood. The total loss in Williamson County is estimated at \$2,205,000 with a death list of 93, including the losses and deaths at Taylor.

Bell County reported a property loss of \$3,700,000, principally of crops, roads, and bridges, and 5 deaths.

Milam County, which receives the run-off from Williamson and Bell Counties, was probably the greatest sufferer from the deluge. The Little River at Cameron stood 4.5 feet higher on September 10, 1921, than it did during the record flood of December, 1913. Measurements were made by Mr. C. W. Lawrence, superintendent of the water works at Cameron. The total damage in Milam County is estimated at about \$6,000,000, and 66 deaths were reported, mostly of Mexicans in the vicinity of Thorndale.

Burleson County, which is just south of Milam County, suffered damage to the extent of \$785,000, but Lee County, which joins both Williamson and Milam Counties, reported practically no loss.

The flood waters from the Little River began to pour into the Brazos just above Valley Junction on Saturday, September 10. The gage at Valley Junction showed a stage of 3.5 feet at 7 a. m. of that date. At 4.30 p. m. the river was up to 25 feet, rising fast, and at 6.30 p. m. bank full. The observer then warned all residents to leave. No gage readings were taken September 11, 12, and 13, but measurements made from marks left by the flood showed that the maximum height was 58.2 feet, only 0.8 foot below the record flood of December, 1913, but 4.2 feet higher than flood of the spring of 1915. The flooded area was approximately 4 miles wide. Cotton and corn were ruined, and railroad tracks and bridges washed out for a distance of 3 miles, suspending travel for six days. There were no deaths. Flood stage at Valley Junction is at 44 feet.

At Washington, near Navasota, the stream began to rise rapidly about 8 p. m. September 10. The initial 24-hour rise amounted to 21.8 feet to a stage of 27 feet at 7 a. m. September 11. During the next 24 hours there was an additional rise of 15.2 feet, and the stream ultimately reached the peak of the flood on the morning of September 14, with gage reading 50 feet. This was 5 feet above flood stage, but 2.9 feet below the flood of April, 1915. At this time the stream varied from 1 to 3 miles in width. The damage is estimated at \$150,000. There was no loss of live stock.

At Hempstead a high-water gage only is maintained on account of the yielding nature of the banks. The maximum stage reported was 40.2 feet, 0.2 foot above flood stage at 7 a. m. September 16. This is 6.3 feet below the flood of April, 1915. The lowest section of the river gage was washed away with the initial rise. The damage from the flood is estimated at \$43,500, including \$1,000 for loss of live stock. The money value of property saved by warnings is estimated at \$100,000. Wallis, Austin County, located below Hempstead, reports \$5,000

damage to cotton and corn, and a saving of 1,500 head of cattle, valued at \$37,500, through the warnings.

Flood stage was not attained at Rosenberg, although the stream was bank full to overflowing near the coast where the land is level and the run-off correspondingly slow. No damage occurred, except that the Freeport harbor entrance had shoaled as a result of the flood and had to be dredged to release a steamer.

Acknowledgment is made of the receipt of reports of damage furnished by county judges of Bastrop, Bell, Blanco, Burleson, Comal, Gonzales, Guadalupe, Hays, Lee, and Wilson Counties.

TABLE 1.—Deaths and losses from September, 1921, floods, so far as reported.

Counties.	Deaths.	Buildings, bridges, roads, etc.	Crops, corn and cotton.	Live stock.	Other damage.	Total losses.
Austin.....	0	0	\$5,000	0	0	\$5,000
Bastrop.....	0	\$2,000	6,000	*	0	8,000
Bell.....	5	500,000	3,000,000	*	\$200,000	3,700,000
Bexar.....	51	5,000,000	*	*	*	5,000,000
Blanco.....	0	0	2,000	0	0	2,000
Burleson.....	0	25,000	750,000	*	10,000	785,000
Comal.....	0	2,000	70,000	*	*	72,000
Fayette.....	0	*	15,000	\$1,500	750	17,250
Gonzales.....	0	1,000	2,500	0	*	3,500
Grimes.....	0	*	150,000	*	*	150,000
Guadalupe.....	0	2,000	20,000	0	*	22,000
Hays.....	0	50,000	20,000	2,500	50,000	122,500
Millam.....	66	*	*	*	*	6,000,000
Travis.....	0	600,000	225,000	25,000	30,000	880,000
Waller.....	0	2,500	37,500	1,000	2,500	43,500
Williamson.....	93	*	*	*	*	2,205,000
Wilson.....	0	15,000	*	*	*	15,000
Total.....	215	6,199,500	4,303,000	30,000	293,250	19,030,750

\* Included in total or other items.

TABLE 2.—Money value of property saved by warnings, so far as reported.

Austin County.....	\$37,500
Fayette County.....	20,000
Waller County.....	100,000
Total.....	157,500

### THE SAN ANTONIO FLOOD OF SEPTEMBER 10, 1921.

By J. H. JARBOE, Meteorologist.

[Weather Bureau, San Antonio, Tex., Sept. 23, 1921.]

On the morning of September 10, 1921, between the hours of 12:30 and 6:00 a. m. the most destructive flood in the history of this section swept through the city of San Antonio. Buildings, bridges, and streets gave way in the path of the flood and great damage resulted. An area, about 6 or 7 miles long and from one-half to 2 miles wide, including the business section, was inundated to the depth of from 2 to 12 feet. Three separate floods merged into one in the southern part of the city. Fifty-one lives are known to have been lost, and property damage was estimated at between four and five million dollars.

*Rainfall in San Antonio.*—A drought of two months' duration was broken when a shower of 0.53 inch fell between 6 and 7 a. m., September 8. Seventeen hours later, between 12:00 midnight and 1:00 a. m. on the 9th, steady rains began and continued until shortly after 11:00 p. m.—a period of about 23 hours. The crest of the flood came through the city two hours after the precipitation ended.

The amounts of precipitation, as measured at the United States Weather Bureau, are as follows:

	7:00 a. m.	7:00 p. m.
Sept. 8.....	0.53 inches	0.01 inch.
Sept. 9.....	3.48 inches	1.90 inches.
Sept. 10.....	1.46 inches	T.
Total, 7.38 inches.		

This shows a total amount of 6.84 inches for the 24 hours ending about 11:00 p. m., September 9th. If the

showers that occurred on the morning of the 8th are included, the total is 7.38 inches.

Records of the rainfall at San Antonio since 1885 show that only on one occasion has the 24-hour amount of September 9, 1921, been equaled or exceeded. This occurred on October 1-2, 1913, when 7.08 inches in 24 hours were recorded, and a destructive flood followed.

At the Weather Bureau station, near the center of the city, 1.46 inches of rain fell between 7:00 p. m. and 11:00 p. m., September 9. However, the rainfall increased rapidly north and west of this point until amounts of 3, 4, and 5 inches occurred during this same period of time at stations located from 2 to 5 miles distant.

On a map of the San Antonio River and its tributaries, accompanying this report, Fig. 1, are located 12 stations at which measured amounts of rain preceding the flood are shown. At five of these stations the precipitation was measured in regular 8-inch gages. See table 2, p. 526. At the remaining stations, including 9 others just outside limits of the map, improvised gages such as cans, barrels, and in one instance a wooden trough, were used. Allowance was made for sloping sides and rounded bottoms where these occurred. With but one exception each of the 21 gages was visited, inspected, and the measurements carefully checked.

In this connection the cooperation of the Engineering Department of the United States Army is kindly acknowl-